The University of Texas at Austin
Aerospace Engineering
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Quantifying, Assessing, and Predicting the Behaviors of the Anthropogenic Space Object Population in Near Earth Space

Space Environment Effects and Impacts

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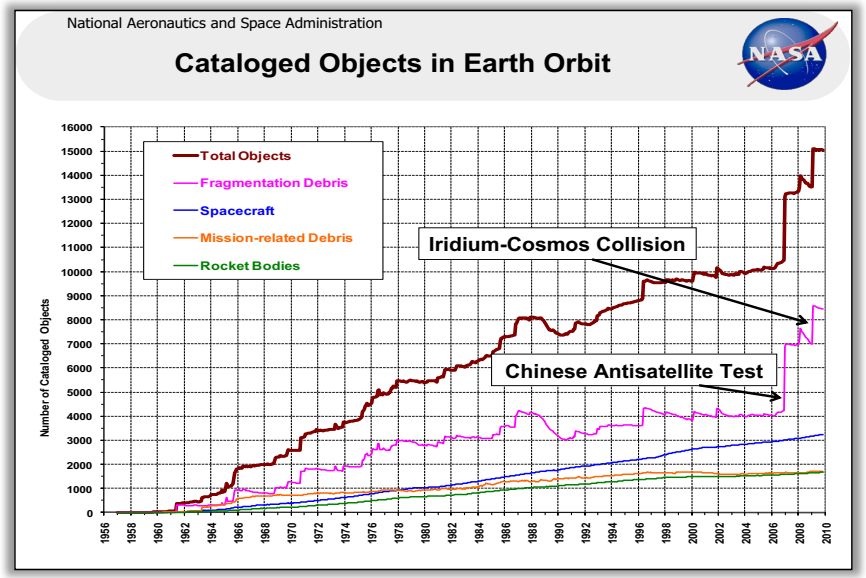
Assumed Space Object Population

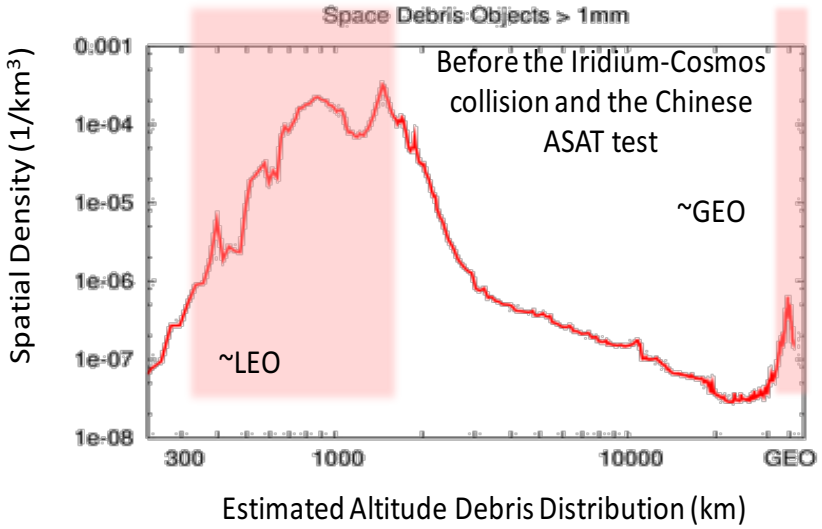


~1200 "Live" objects

~20,000 objects >10cm

~3-600,000 objects >1cm

Space participants are proliferating – 43 countries today



Sources	Sinks
• New Live objects/satellites • All space object weathering leads to flaking, chipping, erosion • Mission/deployment related debris • Gravity fatigue and torqueing self destruction • Dead objects/debris and explosions • Fretting fatigue causing structural failure	**De-orbiting objects:** Space environment and/or gravitationally induced perturbations about *1-3 per day*

Space Domain Awareness: The "Why"

Space Hazard
"A Harsh Environment"

The space environment is hostile and hazardous

- Electronics upset
- Materials age
- Radio waves degrade

The space environment affects the dynamic behavior of anthropogenic space objects

The environment needs to be understood and managed

Space Hazards
"The Safety of Flight"

There are many anthropogenic space objects—many dead, some not

- Paths only approximately known
- Space is more crowded today

Anthropogenic space objects are hazardous to each other

- The probability is low, but the consequences are very high!

Traffic management of space congestion needs to assure safe operations, security, and sustainability

Space Threats
"The Adversary"

Space is contested by adversaries today

- The required methods to address the threat are new
- The methods cross many phenomenologies and disciplines
- As long as we do not fully understand and measure the space domain, there will be places to hide and an ability for us to be deceived!!!

The threat is real, and growing

- We must be able to attribute cause of behavior: intentional vs unintentional

The threat must be detected, understood, and addressed

To Know it, you MUST Measure it; to Understand it, you MUST Predict it!

Effective Space Traffic Management Requires

- Transparency
  - Open and accessible anthropogenic space object and event data sharing
- Accountability
  - We must be able to monitor all behavior and given the evidence, come to common conclusions and infer similar causal relationships
- Predictability
  - Communication
    - Preemptive sharing of details (registering events) for planned events like maneuvers, launches, deployments, etc.
  - Cultural Competency
    - What is Sharia interpretation of the UN LTS Guidelines?
    - Do Israeli satellites maneuver on Shabbat?
    - Bottom Line: Can we predict what any space actor will do for any given space event?
  - Accurate and precisely modeled astrodynamics and space events
    - Ephemerides and related parameters
    - Space weather predictions

Descriptive vs Inferential Statistics

- Descriptive
  - Measures the entire population and describes its distributions

- Inferential
  - Only measures a sample of the entire population
  - Draws conclusions about the entire population from the measured sample by way of resultant data, with an associated uncertainty

Uncertain data cannot provide exact models unless we apply prejudice to remove inherent uncertainty

Anomaly Attribution

Halloween 2003 Storms Retrospective Analysis*

CYBER ATTACK?

RHESSI – spontaneous reset of CPU (3x)

GOES 8 – unrecoverable shutdown of X-ray sensor

Landsat – all instruments turned off or safed

Cluster – some of four spacecraft CPU's reset

Mars Odyssey – MARIE instrument has temperature "red alarm" and is powered off; never recovered

JAMMER ATTACK?

MER 1, MER 2 – Entered sun idle mode after excessive star tracker events

Kodama – safe mode triggered by increased noise on Earth sensor, recovered 10 days later

DIRECTED ENERGY ATTACK?

GOES-12 – magnetic torquers disabled

CHPs – spacecraft tumbled, later recovered

Inmarsat – two spacecraft had speed increases on momentum wheels requiring firing of thrusters

POLAR – despun platform went out of lock 3x; auto recovery after each event

FedSat – stabilized platform started wobbling

COATER SYSTEM ATTACK?

Midori – power dropped, entered safe mode; telemetry lost; total loss

GOES – Electron sensors saturated

GALEX – two UV experiments turned off due to high voltage caused by excessive charge

Chandra – build-up of grease on an optical filter in front of one cameras

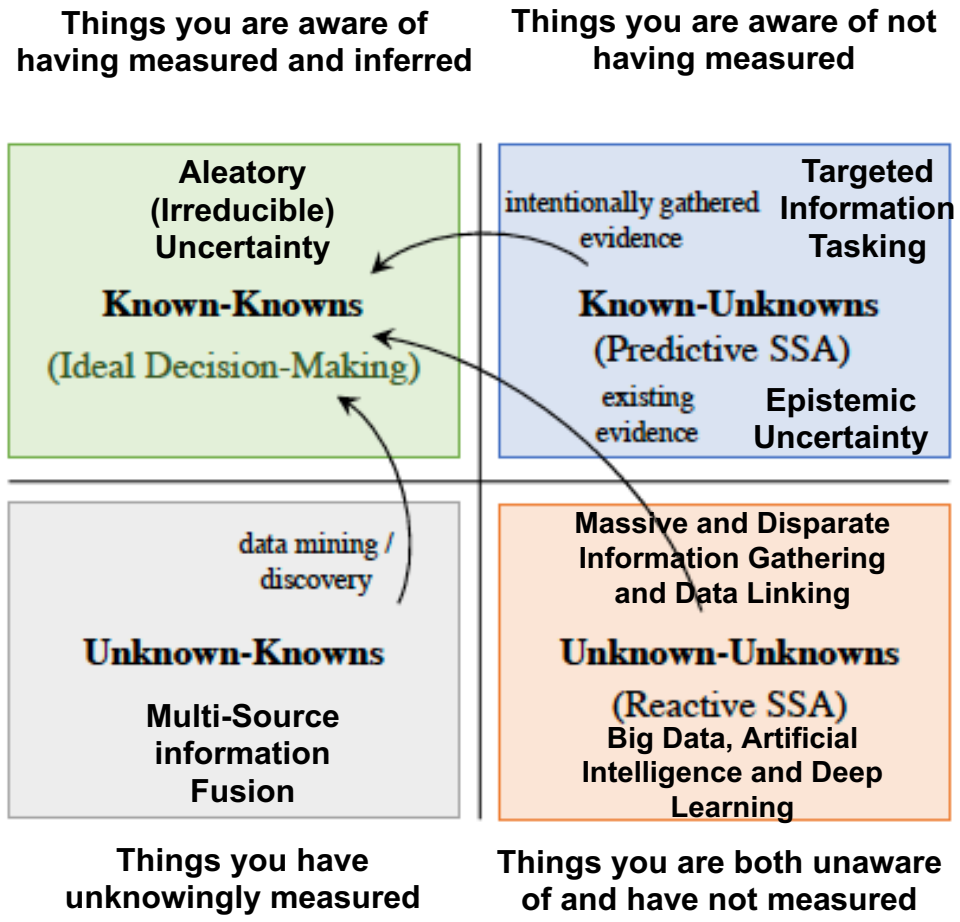
*From: Susan Andrews, "Distributed Threat Warning Study", MIT/LL Conference

What Influences Inferred Space Object Motion

- Actual astrodynamics experienced by anthropogenic space objects
  - Gravitational, particulates, radiative, electromagnetic
- Our models of the astrodynamics
  - Imprecise and inaccurate
- Actual sensor data
  - Noisy and biased
- Our models of the sensor data
  - Imprecisely and inaccurately characterized as compared to actual sensors
- Our choice of inference method
  - Batch, Kalman filter(s), SRIF, Particle, Cubature, etc.

To Know it, you MUST Measure it; to Understand it, you MUST Predict it!

Space Domain Awareness Johari Window



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From Measurements to Understanding

- Measurements yield data
- Data follow distributions (aleatory) or have structure (epistemic)
- Distributions or structure provide inferred models
  - abduction and hypothesis generation
- Models permit prediction
  - hypothesis testing and falsifiability principle
- Prediction reflects understanding
  - surprisal analysis

Maximum Information Entropy

- Maximum possible ambiguity
- Enumerate (abduct) the set of all possible hypotheses that explain the evidence
- Representation that makes the least amount of assumptions
  - Least number of constraints or ascribed prejudice
- Proper Application of Occam's Razor?
  - Least number of constraints or assumptions does not imply simplest explanation

Application of Karl Popper's Falsifiability Principle

- Seek data that can show that these hypotheses are or can be falsified
  - Only remove what has been contradicted or discarded by evidence
- Falsifiability as a demarcation of science
- Hypotheses not falsified are not guaranteed to be true
  - "Absence of evidence is not evidence of absence" Carl Sagan

Application of Surprisal Analysis for Minimum Information Entropy

- Begin with the maximum entropy representation
  - Ensemble of all possible hypotheses that explain the evidence
- Each hypothesis in the ensemble is a belief which acts as an information mass
  - Each hypothesis (belief), if true, prevents the system from achieving maximum entropy
  - Each hypothesis has belief inertia (resistance to change in the face of evidence) whose magnitude is a composite of the dimensions of data quality: accuracy, consistency, completeness, validity, timeliness, uniqueness, etc.
  - A belief will remain unchanged unless it is surprised (unpredicted evidence)
- Surprisal is a measure of the change in a prior belief given new evidence
  - If we predict the truth, there is exactly zero surprisal because the evidence only confirms our belief (hence we reward the belief with least surprisal but something independent of our belief would also yield zero surprisal…we call this unobservability)
- The set of hypotheses yielding the least surprisal through the path laid out by the evidence is the minimum entropy state

Near Earth Space Correlation Pleiades

- Conceptualized by Terentjev (1931) and Berg (1960), Russian Geneticists and Biologists
  - Identifies the cluster (pleiades) of traits and features in a common organism that display correlated developmental and evolutionary processes

- If we treat Near Earth space as one common organism and aggregate all data and information related to it, we could evaluate these holistically and seek to discover its correlation pleiades within the mutual information of these heterogeneous data

- What are the space environment/weather processes that are correlated with specific dynamic and aging processes in the anthropogenic space object population?

- Can we develop a trait-based taxonomy for the anthropogenic space object population based upon species, habitat, and any predation? Birthers, killers, decomposers, removers, etc.?

“Whenever a model is built, it is always proper to ponder the basic scientific question: Is the model really based on the data? Or is an artifact displaying the prejudices of its creator?”

Rudolf Emil Kalman

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